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EARLY DAYS IN RADIO RESEARCH

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SCIENTIFIC RESEARCH within the meaning of the term 'radio', with all its modern applications, is a little over 100 years old; and most of the advances in the field of research have taken place within the past halfcentury.

For example, it was in October 1864 that Prof. James Clerk Maxwell enunciated the fundamental equations of the electromagnetic theory of light and predicted that longer waves, although not detectable by the human eye, could exist and be transmitted through space. We have come a long way from the formulation of these equations to the production of the laser, the equivalent of the radio engineer's continuous-wave source at a frequency within the visual portion of the electromagnetic-wave spectrum.

But, on the way, Heinrich Hertz demonstrated the generation and detection of trains of damped waves on a laboratory scale: their application to practical radiocommunication awaited the development of the loose-filings coherer by Sir Oliver Lodge. After improvement by Prof. E. Branly, this coherer was used by the Marchese Guglielmo Marconi to demonstrate the practical possibilities of wireless or radio signalling by means of electromagnetic waves travelling freely through space or over the surface of the Earth. Concurrently, a Russian scientist, Aleksandr Stepanovich Popov, made improvements to the Lodge-Branly type of coherer; he used this first to detect radiation from atmospheric discharges, and secondly as a means of communication by Hertzian waves, as they were then termed.

It was during the last decade of the 19th century, also, that Prof. Ernest Rutherford used the magnetic detector for receiving signals over a distance of half a mile, and Capt.—later Admiral of the Fleet Sir Henry—Jackson of the Royal Navy was experimenting with wireless communication from ships to land over gradually increasing distances.

1 Admiral of the Fleet Sir Henry Jackson, G.C.B., F.R.S., chairman of the Radio Research Board, 1920–29



All these practical developments culminated in December 1901 when Marconi and his colleagues sent signals from Cornwall, England, to a receiving station set up in Newfoundland. This demonstration of the fact that electromagnetic waves could be transmitted over thousands of miles gave rise to much thought and speculation as to the precise mechanism by which the waves travelled round the curved surface of the Earth; but it was more than 20 years before the scientific phenomena and processes involved were satisfactorily explained.

In the meantime, an increasing number of scientists and engineers in several countries throughout the world had

contributed to the technique and application of what was then implied by the term 'wireless telegraphy and telephony'. It was during these early years, also, that other means of generating and detecting radio-frequency oscillations became available, including the high-frequency alternators of Alexanderson and Goldschmidt, the electric arc of Duddell and Poulsen, the crystal detector of Pierce and Eccles and the thermionic valve of Fleming and Lee de Forest.

Government-sponsored research

The early history of Government-sponsored radio research in Britain is intimately associated with the National

Physical Laboratory, and with the Department of Scientific & Industrial Research (DSIR), which was set up in 1918. In these early days, what may be described as the radio work of the NPL was confined to the extension to high frequencies of the main electrical standards of such quantities as frequency, capacitance and inductance. Probably because it was closely associated with the measurement of time, the standard of frequency soon attained a high degree of precision; and this far exceeded the accuracy of measurement of the other electrical quantities involved in radio research.

under the Department of Education & Science.

At the beginning, investigations on atmospherics were conducted at the Aldershot radio station of the Meteorological Office, which was taken over and extended by the DSIR. A few years later, however, this site had to be given up, and the station was transferred to another portion of Ditton Park, where ultimately it was combined into the Radio Research Station. But, although this station has continued for many years to be the headquarters of activity of the DSIR's radio-research programme, portions of the

ionised regions would be bent in such a way as to follow the curvature of the Earth.

A lecture given in London in 1921 by Prof. J. A. Fleming before the Royal Society of Arts, with the very appropriate title 'The coming of age of long-distance radio telegraphy, and some of its scientific problems', indicated clearly the manner in which the practice of communication had advanced in the absence of a clear explanation of the mode of propagation of electromagnetic waves round the Earth. A year later (August–November 1922), a remarkable diversity of opinion was expressed in contributions to *The Electrician* (London) initiated by Dr. Elihu Thomson, with responses from Sir Oliver Lodge, T. L. Eckersley, Prof. G. W. O. Howe and Prof. A. Schuster. The controversy continued for the next two or three years between the practical engineers developing communications and the theoretical scientists, who were not always agreed among themselves as to the phenomena involved in long-distance transmission.

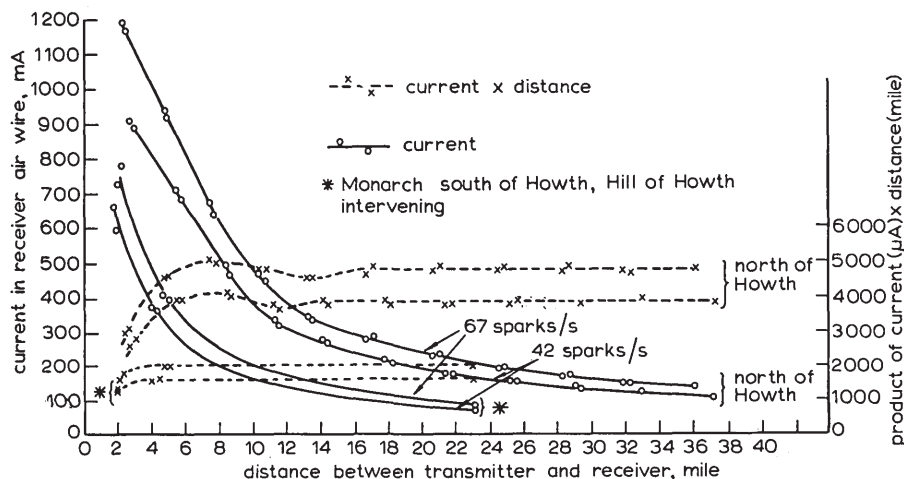
Reflecting layer

The development of sound broadcasting in the early 1920s provided both the need to know more about the fading of wireless signals and the means whereby this could be investigated. At Cambridge University, Dr. E. V. Appleton in collaboration with M. A. F. Barnett, a New Zealand research student, provided the first direct proof of the existence of a reflecting layer in the upper atmosphere.

Two sets of experiments were carried out in December 1924 and February 1925, in which the wavelength (or frequency) of the Bournemouth transmitting station of the BBC was varied while the strength of the signals received at Oxford, about 100 mile away, was observed. On both occasions, the received signals showed successions of interference maxima and minima, which were interpreted as being analogous to the optical interference fringes produced by a Lloyd's mirror system; and this demonstrated the reception of two sets of waves which had arrived by different paths from the transmitting station.

By a simple calculation, these two paths were identified as the direct path along the ground between transmitter and receiver, and the indirect path of waves which had travelled up to an electrically conducting layer and been reflected back to the receiver on the ground. Similar conclusions resulted from a comparison of the signals received at Cambridge, on a vertical wire and on a loop aerial in the plane of propagation, from a transmitting station in London, some 50 mile away.

The results of the Appleton–Barnett experiment were soon confirmed in several ways and under a variety of conditions. Under the encouraging authority of the Radio Research Board, special transmitters were erected, first at a Post Office station near Peterborough, to be replaced by a more permanent installation at the NPL, Teddington, from where frequency-changing signals were emitted



2 Field-strength measurements in HMTS Monarch, Howth to Holyhead

As one of a number of boards and committees set up by the DSIR, the Radio Research Board was established in 1920 under Admiral Sir Henry Jackson (Fig. 1), to provide for research of a fundamental nature in fields where it was lacking and where it would be likely to lead to useful applications. The appointment to the board and its committees of representatives of other civil and defence departments, and, from time to time, of experts from universities and the radio industry, ensured that due attention would be given to problems concerning the applications of radio, as well as others of a more far-reaching character.

Five committees

After making a survey of the experimental work being conducted in various establishments, the board appointed five committees to deal with the propagation of waves, atmospherics, directional wireless, thermionic valves and, by no means the least important, high-frequency standards. At that time, it seemed very appropriate to entrust to the NPL those portions of the work which required facilities and instruments for measurements of the highest precision. Later, it transpired that, for research on wave propagation and directional wireless, more open-field amenities were required; and these were soon provided on land adjoining the Admiralty Compass Observatory at Ditton Park, near Slough, Bucks. Although originally selected in the 1920s for temporary field-experimental work, this site has now become the permanent home and headquarters of the Radio & Space Research Station,

work have been conducted in many other places in the United Kingdom and at some subsidiary establishments in Singapore, the Falkland Islands and Antarctica.

Signal strength

The first two decades of this century were marked by the development of radio signalling as a means of practical communication between stations on the Earth's surface, in ships or in aircraft. While quantitative scientific studies were not very common, measurements were made as long ago as 1912 by W. Duddell and J. E. Taylor on the strength of signals received on board a ship proceeding from Howth, Dublin, to Fishguard, Pemb., from a transmitter erected at Howth. As indicated in Fig. 2, these showed that, up to about 80 mile, the strength of the signals was almost inversely proportional to the distance from the transmitting station. At greater distances, the strength of signal was subject to erratic variations, which later investigation showed to be dependent on the frequency used, the time of day or night, and whether the transmission was over sea or overland.

Ten years earlier, in 1901, Marconi had demonstrated that radio waves could be transmitted between England and the North American continent; and this achievement gave rise to much long-continued speculation as to how electromagnetic waves could travel round the curved surface of the Earth. In 1912, Dr. W. H. Eccles, in a mathematical study of the effect of ionisation on the propagation of the waves, concluded that, if, as seemed likely, the density of ionisation of the air increased with height, radio waves travelling through these

for reception and measurement at Cambridge, over a distance of some 50 mile. In the meantime, two American scientists, G. Breit and M. A. Tuve, associated with the National Bureau of Standards in Washington, had developed a pulse technique for the same purpose; and, by measuring the time of travel of a pulse of radio waves up to the reflecting layer and down to the receiving station, they made similar determinations of the height of the reflecting layer.

This pulse technique was adopted at the NPL transmitter, and, when it became clear that a long-term study of the ionosphere—as the reflecting layer was soon called—was involved, the necessary receivers and recorders were set up at the Radio Research Station, Slough. In due time, the transmitter was also moved to Slough and became incorporated in a combined transmitter-receiver that was the prototype of those in use at ionospheric observatories throughout the world. With the conversion from a string galvanometer to the cathode-ray oscillograph, and from visual to photographic recording, this self-contained equipment has met world-wide demands for studying the ionosphere under all conditions and from periods of a few minutes at a time, to those required by the solar cycle of some 11 years. This long-term research has shown that the ionosphere has a complex structure, with three main reflecting regions, as illustrated in Figs. 3 and 4.

Slough experiment

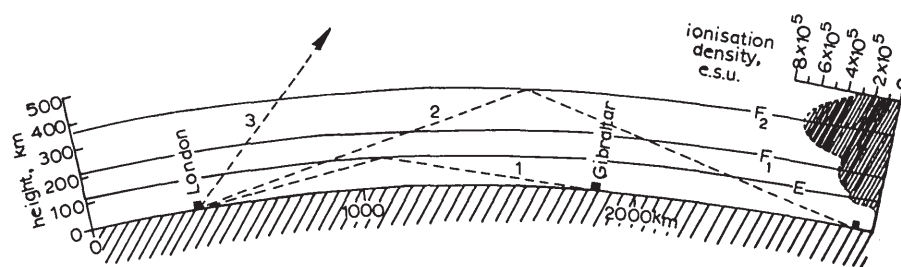
Here I may refer to some parallel experiments carried out at Slough by R. H. Barfield and myself in an endeavour to explain the variations experienced in the use of radio direction finders. A consideration of the relation between the fading of signals received on an aerial and the bearings observed with a closed loop led to a study of the comparative field strength measured simultaneously on a vertical aerial and a vertical loop. It was soon found that the relative signal strength and its variation were dependent on the cosine of the angle of incidence of the waves at the ground. From this it was a simple step to demonstrate that, under the same conditions as were accompanied by signal fading, some of

the radio waves had been reflected from the upper atmosphere at a point midway between the sending and receiving stations.

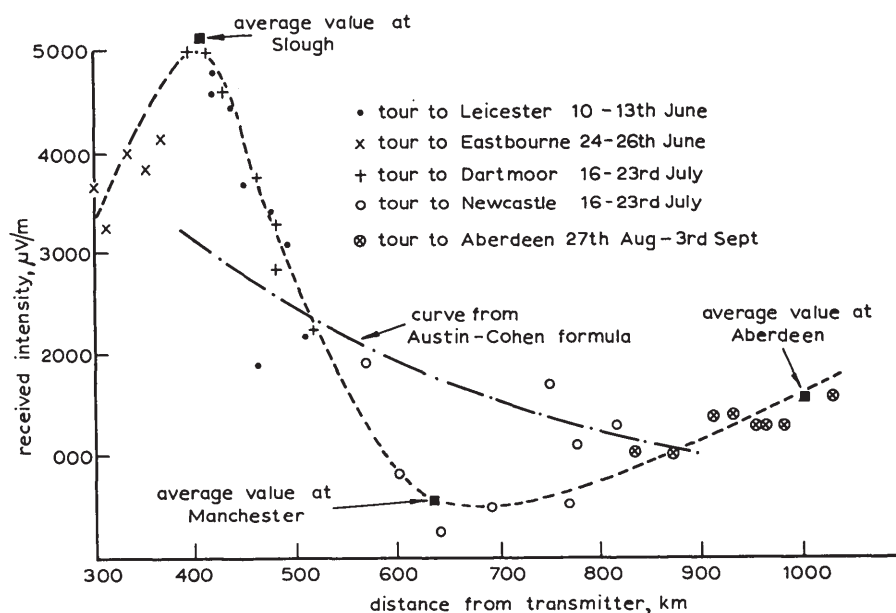
Confirmation was obtained by somewhat more elaborate measurements made with a Hertzian rod aerial, which could

accuracy required in these early experiments.

While experimental investigations on the above lines were in progress, J. Hollingworth was developing more-precise equipment for the measurement



4 The E, F1 and F2 layers of the ionosphere: the diagram shows to scale the Earth's curvature and the levels of greatest electron density in the chief ionised layers; on the right is shown the height distribution of electron density

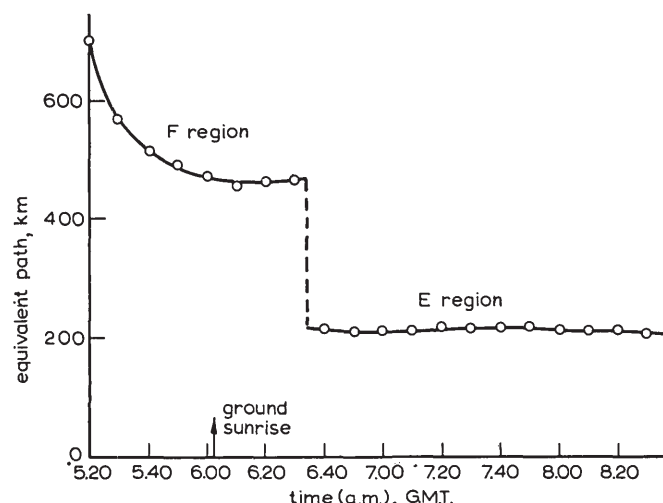


5 Intensity/distance curve plotted from measurements taken with a portable field-strength meter during the summer of 1925

be rotated about both a horizontal and a vertical axis, and by a tuned closed loop which could similarly be oriented about both vertical and horizontal axes. It was realised that such measurements depended to a major extent on the Earth being a very good electrical conductor and so forming approximately a perfect reflector of radio waves. But later investigations, described below, showed that such an assumption was fully justified to the

of field strength at rather longer wavelengths, for frequencies around 30 kHz.

In addition to installing such equipment in the neighbourhood of the universities of Aberdeen, Glasgow and Manchester, a portable field-strength-measuring set was constructed. During the summer of 1925, when conditions were expected to be stable, the daytime field strength of the signals from Paris were measured at a number of points over a distance of about 1000 mile from the south of England to north of Aberdeen. The result was of exceptional interest at that time; for, as shown in Fig. 5, it provided the evidence for the reception of two waves which, by interference, could reproduce a low field at one point and a high field at a more distant point. Thus, for the very low frequencies used, direct evidence was provided of the reflection of these waves from an elevated ionised layer, the height of which was estimated to be about 60 km. The daytime stability of the measured field strength in summer, and its corresponding variability at night and throughout the day and night in winter, have since been demonstrated as being characteristic of the reflection of low-frequency waves from the lower regions of the ionosphere.

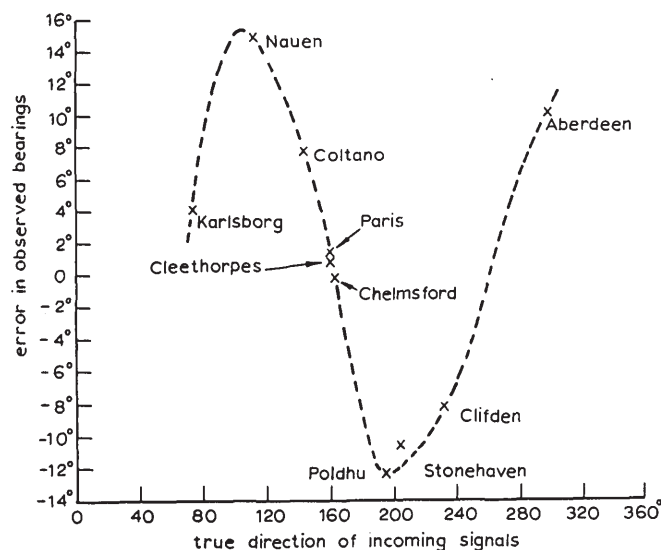


3 Teddington transmissions received at King's College, Cambridge, 21st March 1930

The directional properties of the closed-loop receiving aerial had been appreciated from the earliest days of radio, but its practical development as a useful direction finder operating on the detection of a minimum or zero strength of signal

erected almost on top of an underground sewer laid on a mat of expanded steel about 6ft wide and 300ft long, buried at a depth of about 8ft.

Another result of this early work was to confirm the nature and magnitude of



6 Mean error in bearing observed at Aberdeen on various transmitting stations

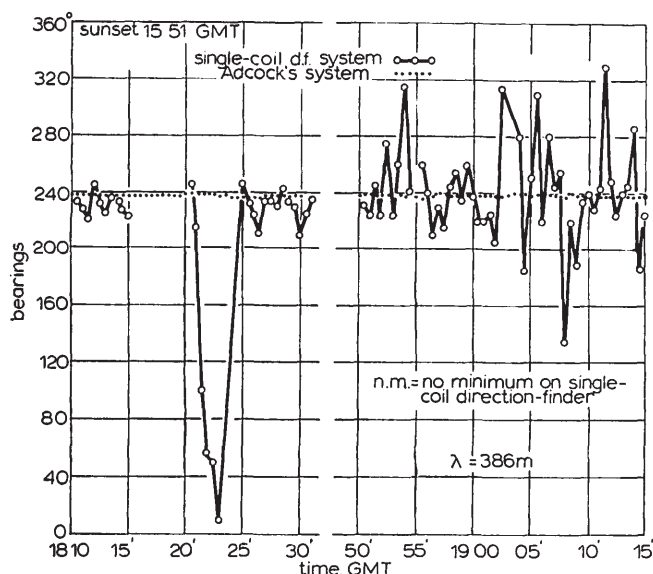
had to await the introduction of valve amplifying receivers. In 1920, the newly established Radio Research Board decided to erect a number of identical radio direction finders in various parts of the British Isles for studying their performance under a variety of conditions.

A preliminary study of the effects of obstacles such as trees and metallic structures soon showed the precautions needed to ensure that the readings of the direction finders were free from local errors. While most of the sites selected were found to be free from such errors, the one erected in a large open field near Aberdeen University soon showed considerable fixed errors in observations on various European transmitting stations. The resulting curve of error plotted against the true bearing is shown in Fig. 6, and it was soon appreciated that this was similar to the normal quadrantal error curve experienced with a direction finder installed on the deck of a metal ship.

the errors arising in direction finding from the change in conductivity of the Earth's surface when the radio waves cross a coastline at a grazing angle. As previously observed by T. L. Eckersley, such errors can be as much as 3-4° at frequencies approaching 1 MHz; but they were found to decrease to less than half these values as the frequency was reduced towards 100kHz.

Variable errors

Apart from the more-or-less fixed errors mentioned above, a more general result of the main investigation was to establish the conditions under which the closed-loop direction finder was subject to variable errors which depended generally on frequency, on distance of transmission, whether overseas or overland and on time of day and season of the year. At medium wavelengths, erratic variations of the bearings were encountered, usually from an hour or so before



7 Observations of bearings on Bourne-mouth, 10th December 1925

The analogy prompted a detailed examination of the field site at Aberdeen, and it was discovered that the hut containing the direction-finder had been

erected at the eastern end of the path until a similar period after sunrise at the westerly end. At greater wavelengths and longer distances, the range of variation

was much less, particularly during the summer months. With the understanding of the nature of the propagation of radio waves by way of the ionosphere described above, it became clear that these apparent departures of the observed bearings from the great-circle path from the transmitter were the result of the horizontal component of the downcoming waves.

In this connection, it was recalled that in 1919 F. Adcock had described in a patent his proposals for the substitution of vertical aerials for the two closed loops of the Bellini-Tosi direction-finding system in order to overcome and remove what was termed 'aeroplane effect'. This conception arose from the errors observed with the loop direction-finding system when receiving signals from aircraft at appreciable angles of elevation. By arranging that only the vertical elements of the aerial system were exposed to the influence of the arriving waves, the cause of what was alternatively termed 'night effect' or 'polarisation error' could be removed.

This is the principle of the spaced-vertical-aerial direction finder, in which the aerial can be either of an H system, with the horizontal members compensated, or as a $\square$ type in which the horizontal leads connecting the vertical aerials to the receiver are appropriately screened. The immediate success attained in adopting this system is illustrated in Fig. 7, in which the extensive errors of the loop direction finder are compared with errors of 1° or less in the bearings taken simultaneously with the Adcock spaced-vertical-aerial direction finder.

Before closing this section, it may be mentioned that it was in course of restricting the pickup of signals in direction-finding systems that the principles of screening both the aerial connections and the receiver, including the local oscillator, were clearly established. This included an examination of the relative advantages of screening with wire netting, and solid-metal sheets with mercury seals where necessary.

Atmospherics

In the early days of wireless development, a variety of names was given to those stray noises, Xs, clicks or grinders, which were to be heard in a receiver and constituted an interference with the desired signals. With the passage of time, the generic term 'atmospheric' emerged, and this, according to the British Standard glossary, is defined as 'electromagnetic radiation arising from a natural process in the Earth's atmosphere and the disturbance produced thereby in a radio receiver'. The comment is added that 'a lightning flash causes an atmospheric'. Thus may be summarised the results of some 70 years' research in this field of radiophysics associated with natural phenomena.

The study of these natural electric waves was begun in about 1895 by A. S. Popov, who has already been mentioned in connection with the earliest experiments in radiocommunication. Various observers soon learnt to associate these atmospherics with local thunder-

storms; and in 1910 Dr. W. H. Eccles, in London, and H. Morris-Airey, in Newcastle upon Tyne, made simultaneous observations both by day and by night. On comparing their records they found that some 70% of these corresponded in time; they deduced that the prevailing source was at a distance much larger than that between the two observing stations.

At about the same time, H. J. Round and his colleagues, who were developing trans-Atlantic signalling, experienced difficulties caused by the incidence of atmospherics, particularly during afternoons in summer. In 1912-13, a radiotelegraphic investigations committee of the British Association analysed a large volume of observations collected from many parts of the world. Its report pointed out that atmospherics heard during the hours of darkness were louder and more numerous than those experienced in daylight, except on those occasions when there were thunderstorms in the locality of the receiver.

Thunderstorms

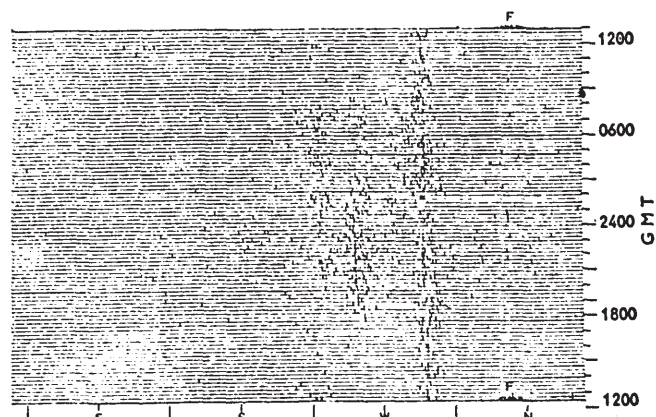
The latter aspect attracted the attention of meteorologists, and it was from this standpoint that R. A. Watson-Watt first became interested in an extended study of atmospheric disturbances. Using radio direction finders to determine the direction of arrival of the most prominent atmospherics, it soon proved possible, in a few cases, to locate the source of the disturbances and to relate these subsequently to the meteorological reports on the areas of thunderstorms. With the introduction of valves in wireless receivers, giving a high effective amplification, it was natural to find that the frequency of occurrence of audible atmospherics was enormously increased, owing to the radius of the source having been extended from hundreds to thousands of miles.

A further marked advance in the available technique was the introduction of the cathode-ray oscillograph, which, in the early 1920s, was regarded as a high-grade scientific instrument not commonly found in physics laboratories. But its introduction into the study of atmospherics marked a significant advance. Not only was it possible for observers many miles apart to make simultaneous recordings of the direction of arrival of individual atmospherics, but its ability to display the waveform and duration of the arriving disturbance was soon appreciated and applied.

With the active encouragement of the Radio Research Board, E. V. Appleton and R. A. Watson-Watt initiated a detailed study of the waveform, intensity and duration of atmospherics at an Air Ministry station at Aldershot, which was subsequently transferred and incorporated in the Radio Research Station at Slough. A cathode-ray oscillograph was used in the early 1920s to delineate the waveform of the e.m.f. induced in an aperiodic aerial circuit by the arriving atmospheric. In this early work, the image was observed visually on the oscillograph screen and accurately sketched by hand. From some 600 typical

waveforms so obtained, nearly half were found to be of an aperiodic type and of an approximate duration between 0.5 ms and 3-4 ms, and in some cases with a superimposed ripple of frequencies from 3 kHz to 30 kHz. The other half of the observed waveforms were of a quasi-

8 Record of atmospherics received on narrow-sector recorder, 28-29th January 1933



aperiodic type, seldom comprising more than a single cycle of oscillation.

To assist in locating the origin of these atmospheric disturbances, Watson-Watt and his colleagues developed what was termed a narrow-sector directional recorder. This comprised a frame aerial tuned to a low frequency and rotated at 4 rev/h. Any impulse received on the arrival of an atmospheric was recorded on a chart which rotated with the aerial. The recorder was driven automatically, and a typical daily chart is illustrated in Fig. 8, showing the diurnal variation in direction of arrival of the main streams of atmospherics at the receiving station.

Westward drift

These results gave a major advance to our knowledge of the frequency and distribution of direction and intensity of the atmospherics received in the United Kingdom, and they served to extend the observations made by T. L. Eckersley and K. W. Tremellen during a voyage made by the latter from Australia to England in June-August 1923. Their observations confirmed previous conjectures that the most prevalent sources of atmospherics were the large continental land areas, particularly in tropical latitudes, such as Africa, South America and parts of Asia. The bearings taken on board the ship also indicated that these sources moved westward approximately with the Sun, and that the rate of production of atmospherics reached a daily maximum at about 1500h local time. These studies provided an explanation of the clockwise drift of the prevalent direction of atmospherics observed in England.

In the first decade of the present century, most of those working on wireless problems were intent on extending the range of practical communication, rather than on conducting scientific studies of the mode of propagation over the Earth's surface.

The development of the British sound-broadcasting service provided both the incentive to learn more about the propagation of radio waves along the ground, and the means of studying this problem. In 1926, J. A. Ratcliffe and M. A. F.

Barnett described the results of measurements of the attenuation of signals in short-distance overland transmission from both the London and Daventry stations of the BBC on wavelengths of 364 m and 1600 m, respectively. For distances greater than about ten wavelengths from the

transmitter, the results showed close correlation with those obtained from Sommerfeld's theory, by assuming certain values for the resistivity of the ground, which turned out to be about three times as great for the area around Daventry as for that around the London station.

The following year (1927), R. H. Barfield described the results of a comprehensive examination of the field strength radiated from the London station in seven different directions and over distances ranging from 5 mile to 100 mile. The results were presented in a paper published by the IEE in the form of, first, a series of attenuation curves for the individual directions, and secondly, in a radio contour map comprising closed curves of constant field strengths round the area of London and the Home Counties. Again the results were compared with those calculated from Sommerfeld's theory, and the apparent resistivity of the Earth's surface estimated. This varied for the seven directions from about 0.2×10^8 e.s.u. to 1.0×10^8 e.s.u.

A subsidiary investigation showed that part of this change with direction of transmission might be due to absorption by trees, viewed as vertical bad conductors in the paths of the waves. While this may have a direct and local influence on the effective resistivity to which surface-wave transmission is exposed, there are many other factors to be considered, such as steelwork in buildings, overhead wires and, by no means negligible in densely populated areas, a large mass of tuned receiving aerials for sound broadcasting.

Field tilt

It is convenient here to refer to some earlier measurements of the effective practical value of the conductivity of the Earth, carried out in association with Barfield by means of a tilting-rod aerial. When electric waves are propagated over the surface of a perfect conductor, the electric force is always at right-angles to the surface. For imperfect conductivity, however, the electric force is subject to a forward tilt from the normal position; and, as shown by Zenneck in 1907, when both the permittivity and conductivity are

of importance, the electric field is of the form of a rotating vector terminating in an elliptical locus in the plane of propagation of the wave. The angle of forward tilt of the electric field or of the major axis of the ellipse can be measured by a suitable rotating-aerial system.

Using this method in an experimental survey carried out in southern England gave conductivity values ranging from 0.5×10^8 e.s.u. to 4.7×10^8 e.s.u. Other measurements carried out at the Radio Research Station, Slough, over a period of several months gave a mean value of 0.9×10^8 e.s.u. for the conductivity at frequencies in the region of 750kHz. Later measurements carried out by R. H. Barfield and G. Munro at a neighbouring site and at a frequency of 19MHz gave conductivity values ranging from 0.5×10^8 e.s.u. to 2.5×10^8 e.s.u.

Soil measurements

As already mentioned, the development of sound broadcasting on medium waves attracted fresh interest in a detailed knowledge of the electrical properties of the ground; and the application of short waves to both communication and broadcasting services made it necessary to extend our knowledge of these properties to higher frequencies.

In the early 1930s, it was considered desirable to obtain more complete information in this field; and the development by my colleagues, F. M. Colebrook and R. M. Wilmotte, of a laboratory method of measuring resistance and reactance at radio frequencies was opportune in providing the required technique. Samples of the soil concerned, which varied from moist loam to coarse gravel or dry sand, were inserted as the dielectric in one or other of a number of capacitors designed for the purpose; and the resistance and reactance of the capacitor were measured over the frequency range 100–10000kHz. Additional measurements were made with a standard type of capacitance bridge through the audio-frequency range to a power frequency of 50Hz.

First, with samples of soil taken from four sites within the grounds of the NPL, the conductivity and relative permittivity were measured, together with the moisture content on different days. The measurements were then repeated on similar samples at various stages during the extraction of the water content in an oven. In this way, the general relation was established between the electrical properties and moisture content for this type of soil.

In the next phase of the investigation, samples of soil were extracted from various sites of Post Office and BBC stations either in existence or projected. Samples for measurement were extracted from some 14 sites in Great Britain at depths ranging up to 10ft, and in one case—Droitwich—300ft. The results were of great interest in showing, first, that, where the soil was sufficient to support vegetation, the conductivity value was usually between 0.5 and 3 or 4×10^8 e.s.u. But below the surface, the conductivity was greater for clay subsoils and much

less for dry sandy sites, or those at which slate or granite occurred. For some of the latter cases, the conductivity measured was less than 10^{-4} of its value at the surface and was found to be of the order of 10^3 – 10^4 e.s.u. These occurrences were accompanied by a decrease in the relative permittivity from a normal value of 40–80 at the surface to 5–10 at several feet below.

At the time of these measurements, special interest was attached to the site of the BBC station at Droitwich, which was then in the early stages of construction. Here it was possible to have samples extracted from depths down to 300ft. These samples varied from red clay and loam at the surface, through clay at first mixed with stones, and then at depths below 100ft, a mixture of red clay and salt was obtained. As a consequence of this unusual composition, the conductivity rose from a value of about 2×10^8 e.s.u. at the surface to about 100×10^8 e.s.u. at depths of 150–200ft. There was a similar increase in the relative permittivity, which became difficult to measure accurately owing to the high conductivity of the samples extracted from this depth.

In an associated investigation of the electrical properties of seawater taken from the English Channel, the conductivity was found to range from 400×10^8 e.s.u. to 550×10^8 e.s.u. over the frequency range 0.5–10000kHz. At such high values of conductivity, the relative permittivity is not significant at the high frequencies in use. But the close relationship between the measured conductivity of seawater and of the salt-laden clay below the surface at Droitwich is of great interest.

Alternative technique

Some years later, an alternative technique for determining the electrical properties of the ground was used by J. S. McPetrie and J. A. Saxton. In this method, a horizontal transmitting aerial was placed at as great a height as convenient vertically above a parallel horizontal receiving aerial. By arranging the oscillator in close proximity to the associated transmitting aerial, all radiation could be assumed to originate from the latter and to be indicated by an ammeter at its midpoint. The receiving system was made as simple and as small as possible, and comprised a dipole aerial with two noncontact thermojunctions in series to measure the current at its centre. In addition to obtaining greater sensitivity, the use of two thermojunctions increased the resistance of the aerial, and so reduced the effect of the variation in its radiation resistance as the height of the receiving aerial above the ground was varied. Measurements were made for heights varying from 50cm to 3m, which, for the wavelength of 5m used, gave one complete cycle of change of received current, owing to the interference between the direct field and that arriving after reflection from the ground. From such curves, the electrical characteristics of the ground were measured at a number of sites, and for different conditions of

the surface, including any grass or other vegetation present.

From the title of this article, it will have been obvious that it was my intention to limit it to a survey of the first 15 years or so (1920–35) of the branch of radio research with which I was formerly associated. At the end of the period under review, the establishment and staff concerned were becoming increasingly involved with other major government departments in problems associated with defence. During the decade 1936–45, the scope of the whole field of activities of radio research and development was enhanced on an enormous scale by its association with the Second World War. Most of the advances made during this period were reviewed in a series of symposia held from 1946 onwards; and the resulting papers were published in *Proc. IEE*.

Steady expansion

The Radio Research Station acquired in 1957 a new and more permanent basis on which it has thrived and expanded steadily during the past decade. It was on the 20th June 1957 that the present buildings at Ditton Park, Slough, were formally opened by Sir Edward Appleton. This was indeed very appropriate, since Appleton had been associated with the work and organisation of the DSIR since the earliest experiments in the department's radio-research programme. The inaugural ceremony assumed additional significance in view of the events which took place shortly afterwards during the International Geophysical Year from the 1st July 1957 to the 31st December 1958.

Three months later, on the 4th October 1957, the first artificial Earth satellite was successfully launched by the Soviet Union into an orbit which was alternately below and above the main regions of the ionosphere. Within 24h, bearing observations were being made on a c.r.t. direction finder at Slough on this satellite which transmitted suitable identifying signals on a frequency of 20MHz. This marked the beginning of a new and expanded programme of research on matters associated with the Earth, its atmosphere and the space beyond. In due course, it became clear that the scope of the station at Ditton Park, Slough, had extended beyond the meaning of the original term 'radio', and, on the 1st April 1965, the name of the establishment was changed to the Radio & Space Research Station, the responsibility for which was transferred to the Science Research Council of the Department of Education & Science.

Over 45 years had elapsed since the first site at Ditton Park had been used by two or three scientists conducting certain experiments in direction-finding techniques. The number of staff engaged is now about 250, and the scope of their research programme is much more diverse than that which Admiral of the Fleet Sir Henry Jackson and the members of the first Radio Research Board had so carefully scrutinised nearly half a century ago.